Step Towards Monitoring Intelligent Agents in Healthcare Information Systems

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Abstract. A platform for establishing interoperability between heterogeneous information systems implemented in a hospital environment is more a requirement than an option. The Agency for the Integration, Diffusion and Archiving of Medical and Clinical Information (AIDA) is an interoperability platform designed specifically to address the problem of integrating information from multiple systems and addressing interoperability, confidentiality, integrity and data availability. This article focuses on the relevance and need for such vigilance, finding and designing effective new ways to establish them. This study culminated in the creation of AIDAMonit, a surveillance platform developed and tested by ALGORITMI Center researchers, which has shown promise and is extremely beneficial for the well-functioning of the health facilities currently using the AIDA platform.

Keywords: Health Information Systems (HIS), Intelligent Agents, AIDA, Interoperability, Monitoring, AIDAMonit.

1 Introduction

Thinking about today's society, everything around it involves technology. The idea that the human being has changed with the technological evolution is a little bit frightening, but perhaps it is the most realistic thinking of today. Over the years Information Technology (IT) has been profoundly embedded in society, to the point that it has dramatically altered mankind's way of thinking and living in such a way that every day-to-day activity depends on the proper functioning of technologies.

In recent years, IT has emerged in several areas and healthcare is no exception. IT is a very broad concept with applicability in many industries. Thus, the clarification of the term is important for the acceptance of its use by institutions and its professionals. So, IT is the set of all activities, solutions and human and/or computational resources that allow access, consultation, management and use of information. Part of the success of IT, in the health area, has to do with the correct acting of Health Information Systems (HIS). They are responsible for the acquisition, processing, and presentation of all information

about the institution and its services. For this, they have tools to improve the care-giving in an efficient and sustainable way [24].

In the healthcare area, the treatment and processing of information has changed quite a lot, from the traditional way of recording all the information in paper to its electronic register. Therefore, nowadays the HIS are already intrinsic or even determinant in the success of the hospital delivery of care. The use of this type of systems is not only beneficial for patients, but also for health professionals throughout the healthcare community, since it will ease several everyday responsibilities involved in their work [10].

It is imperative to make quick and quality decisions in the health sector as these are almost always related to human life. Therefore, medical decision-making needs to integrate the best available evidence with the experience of clinical professionals and the specific values regarding the patient health status [9][13]. Often, in the absence of timely access to high-quality information or even when facing difficulties in constructing a functional historic process of the patient in question, the health professionals are obligated to make decisions based solely on their experience and intuition without considering the facts and information required [9][1]. Obviously, without appropriate access to relevant data, practically no decisions on procedures, diagnostic, therapy, and others can be made without occurring medical errors or other problems, which may result in fatal consequences for patients. This difficulty can be overcome through the implementation of Clinical Decision Support Systems (CDSS), which are based on medical knowledge to assist clinicians in the elaboration of diagnoses and in the decision-making of therapies through the analysis of patient specific clinical variables [23].

In a more technical perspective, CDSS can retrieve relevant documents, create and send alerts or recommendations to patients or healthcare professionals, organize and present relevant information on dashboards, diagrams, documents, and reports, in order to ease, speed up and improve the clinical decision-making [7][19]. Accordingly, these systems should consider information from various systems and platforms implemented in the health institution that due to their diversity constitute another weakness. Thus, the primary objective for the solution of all these problems is the implementation of interoperability platforms in an effective way. These platforms should be based on intelligent agents that interact with each other and organized in robust and efficient architectures, so that the access and interpretation of the information is almost immediate.

The remainder of the paper is organized as follows: Section 2 includes a brief description of intelligent agents, from its definition to the advantages of its individual or multi-agent use. The following section, section 3, describes the AIDA platform, its main characteristics, operation, architecture and vulnerabilities. Subsequently, section 4 explains the worth, the significance and the impact of monitoring computational applications, focusing on the description of the proposed solution, AIDAMonit, a platform for efficiently monitoring the behavior of the intelligent agents that make up the AIDA platform. Finally, sections 5

and 6 discloses the proof of concept and the main conclusions as well as some perspectives for future work.

2 Intelligent Agents and Multi Agent Systems

Intelligent agents have been popular since the middle of 1990, and at this time were defined as a paradigm that represented "the next significant breakthrough in software development" (Sargent, 1992). Since then, the concept and application of this invention has been extended and is now widely used in various fields of science and research [12].

Agents must be capable of operating effectively in dynamic environments where they interact and cooperate with each other. To achieve this, architectures must allow agents to be compatible in order to communicate with other agents and offer services to one another[6]. As the name implies, a Multi Agents System (MAS) consists of two or more agents that have the ability to act autonomously at the same time as they interact with each other. In this interaction, communication protocols are needed so that the agents can efficiently cooperate, negotiate, compete and coordinate [4][14][11][18].

These systems aim to construct and implement robust logic models, capable of resolving large-scale problems. Thus, and since each agent will simultaneously have autonomous activities and asynchronously cooperate with other agents, it is necessary to implement an architecture so that communication, made by the Internet or local network, can exist. The architecture of these should be distributed, but as simple as possible, to ensure communication and interoperability between different applications [23]. In the hospital environment, the MAS stood out due to their ability to solve problems since they communicate and operate for common goals.

The AIDA platform was developed according to these principles, this subject will be discussed in section 3.

3 AIDA

In Healthcare, access to information in a fast and effective way, is a determinant factor for the reduction of medical errors and the consequent improvement of the care provided. However, as much as desired this goal is, it has not yet been achieved much due to the individuality and heterogeneity of the different health information systems. Although these systems increase the quality of the health services, they are developed in an isolated way, failing in the capacity to interact together effectively.

IEEE defines interoperability in healthcare as the "ability to communicate and exchange data accurately, effectively, securely and consistently with different information technology systems, software applications, and networks in various settings and exchange data such that clinical or operational purpose and meaning of the data are preserved and unaltered" [25]. The benefits of implementing interoperability in healthcare facilities and the consequent homogeneity

among HIS are countless. Such benefits include better information quality by single patient identication, time reduction in diagnostic and appointments, since physicians have access to relevant information whenever and wherever they need it, a correct association between all the information systems and, consequently, collaboration at local, regional, national and international level.

The process of implementing interoperability in health organizations is even more difficult because each specialty has its own particularities as well as different methods. Interoperability among systems is one common and comprehensive interest within the entire scientic community. In recent years, the group of Artificial Intelligence (AI) of the University of Minho dedicated itself to building a platform to answer all these needs, the AIDA.

The Agency for Integration, Dissemination and Archiving of medical information (AIDA) is the result of many research partnerships between the University of Minho and several Portuguese health units, including the Centro Hospitalar Universitário do Porto (CHUP). AIDA is a complex system consisting of specialized and straight forward intelligent agents, that seeks the integration, dissemination and archiving of large volumes of data from heterogeneous sources (e.g. computers and medical devices) and the uniformity of the clinical systems [21][16][17][8]. This platform was designed to aid medical applications, their main subsystems, and functional role, as well as to control the entire flow of information through a network of intelligent information processing systems. AIDA uses a multi-agent architecture of the type service-oriented architecture (SOA) to ensure interoperability between various information systems [4][3][20][15]. AIDA is implemented in five health institutions throughout Portugal and has a paramount influence in the quality of the services provided by the healthcare professionals, and it is already installed and in use in five health institutions . Accordingly, all its components must have a form of monitoring and prevention of failure, so that AIDA is available 24 hours a day, every day of the year, to ensure efficient health care delivery. This allows to implement interoperability in a distributed environment according to different types of agents that have very distinct scopes and functions, inside the platform.

The systems that constitute the platform are:

- Integrated Hospital Information System (SONHO) - Emerged in the decade of 90 with the philosophy that a patient only has a unique identification number. It is defined as an integrated hospital information system whose main objective is to support the hospital administrative services, focusing on the display, generation and archiving of information that will be exported for statistical purposes [2].
- Sclinical Hospital – A system that arises from the combination of two smaller ones, the Medical Support System (SAM) and the Nursing Practice Support System (SAPE). This merge occurred in 2013 and resulted in an application centered on the end-user, which can be used by all health professionals, without any division between medical and nursing information.

– Electronic Clinical Process (PCE) – Emerged in 2007 and is a repository of the patient's clinical history. The records have a format already prepared to be processed by computers using the Health Level Seven (HL7) protocol.

Not only the structure of the messages and the type of fields contained in them are necessary for the complete understanding of a message. That is, for the absence of ambiguity, also the meanings, the context and the relations between the different terms must be known and used by both parties in communication. In health institutions, standards are considered the main source for ensuring interoperability between HIS. The HL7 protocol is perhaps the most internationally recognized and is a major contributor to interoperability in health facilities. HL7 is a set of standard formats that define a message structure to exchange information between different heterogeneous hospital applications [15][5][22]. In short, this is used to enable communication from application to application through well-established messages. There are several message templates, each with its own structure and fields. Each message has its own structure and consists of an accumulation of multiple threads that represent a logical grouping of data fields.

The security of the AIDA platform is fundamental because it is a platform associated with healthcare, and, consequently, must be available 24 hours a day, every day of the year. Currently, it is installed in five Portuguese hospitals, including the CHUP, and even a short period of shutdown can bring serious and devastating consequences to the health organization, either directly in the management of resources, and/or indirectly in the quality of the services provided and consequently in the health status of the different patients. Therefore, the prevention of failures as well as the monitoring of the AIDA platform is indispensable and of extreme value to the health institutions.

4 Monitoring System - Platform AIDAMonit

The concept of monitoring, according to the Portuguese dictionary presupposes "Accompany through a monitor", "supervise", "evaluate" or even "Look carefully". However, for computer systems, monitoring presupposes continuous supervision. Regarding intelligent agents, that supervision shall ensure that agents are active and perform their duties efficiently. Efficient monitoring of a given system is only possible if the knowledge about it is consistent and complete. Thus, to achieve successful monitoring, it is necessary to conduct a careful study of the system to identify its greatest vulnerabilities and even the most likely failures to occur. With this identification it is possible to develop procedures to prevent the occurrence of failures.

Concentrating on the main objective, that is, the prevention of system failures, the first step is, in fact, an efficient monitoring process. This process should collect all data relevant to the knowledge of the system and ultimately the prevention of failures. In addition, there may be a middle layer between system monitoring and fault prevention to predict failure. To obtain and process information, the monitoring cycle should move from collecting and storing data in the

database to processing and discarding information on a platform or something similar.

Over the years, several systems have been developed to monitor databases, machines and even intelligent agents of the AIDA platform. But a large part does not perform continuous monitoring. Instead, there is periodic monitoring, for example, every 10 minutes. Therefore, considering that monitoring can directly improve resource management and indirectly patient care, it would be highly beneficial to perform it in real time. To this end, the authors have developed a platform for the monitoring of intelligent agents, in real time and continuously. The main purposes are to monitor the activity of the various agents that constitute the AIDA platform, to quickly detect errors and inconsistencies, as well as to identify agents that take longer than usual to perform their function. In addition, the platform allows to monitor individually (by agent) or collectively (by server) and will also present various statistical data to those who know how to improve agent performance.

The developed monitoring platform features a three-base architecture, as it shows on Figure 1: the database (where the necessary information is stored), a restful api web service programmed in JavaScript, using the Node.JS interpreter, and a browser-accessible client interface developed in ReactJS, a library also in JavaScript. The process starts with a request by the client (User Interface), depending on this request a connection to the database is made through the call. After the connection is successful, it is possible to make queries, in SQL to select the desired data. Finally, the web service transforms the data obtained in the json format and these are sent to the customer.

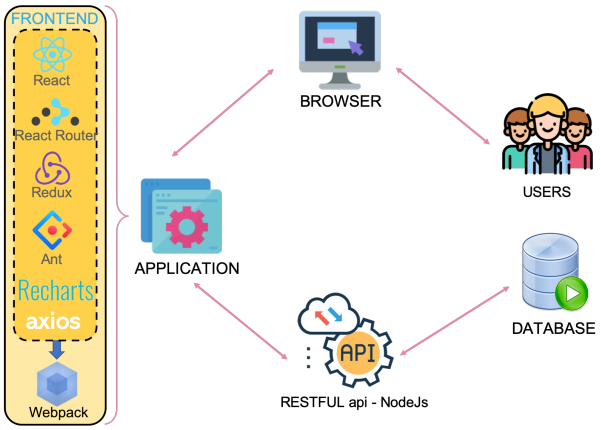

Fig. 1. Web application architecture.

This architecture results in a platform composed of a side menu that gives access to two different modules: SIL and HL7, which are services of the AIDA platform. Figure 2 shows the general layout of the web platform, in which each

of the services has a division of four sub-modules - Panels, Tables, Agents and Servers. Each module is essential for the proper monitoring, detection and correction of any errors that may occur in the agent's software, improving the provision of hospital services, as well as facilitating the daily work of the professionals who have the task of monitoring the continuous behavior of AIDA's intelligent agents.

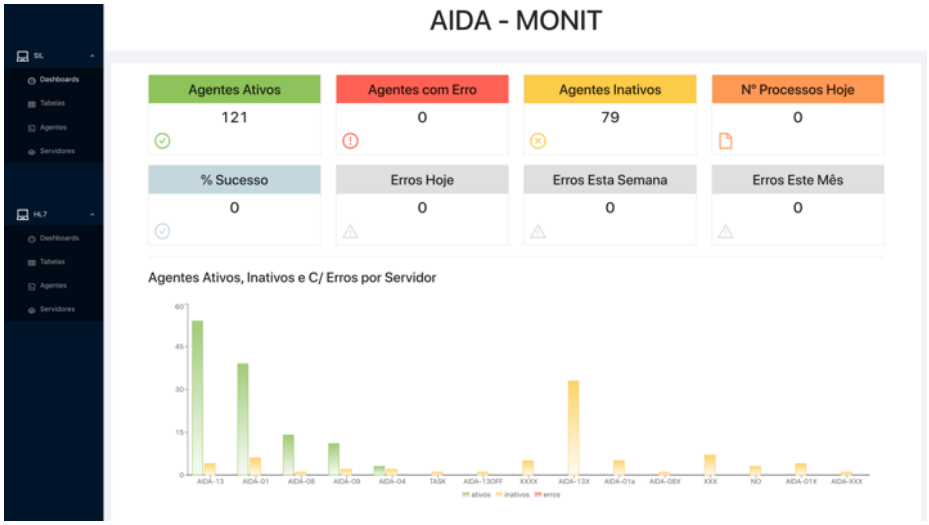

Fig. 2. Global view of the web application interface.

The development of AIDAMonit culminates in the construction of a work environment, full of interactive panels, charts, tables and statistics so that the hospital system information team can accurately consult and manage the activities of the intelligent agents that make up the AIDA platform. Perhaps even more important, this team will be able to observe the occurrence of errors in a timely manner, think and perform ways to resolve them quickly, as well as anticipate their occurrence In order to increase the performance of this technology.

The modules of both services are quite similar, with only distinct sources of information. Therefore, in the dashboards module all the information properly processed, in the form of graphs, is concentrated so that the analysis is quick and effective. The other modules contain detailed information available for consultation.

5 Proof of Concept

Any research project that is aimed at its implementation must pass a proof of concept where questions such as "Is this technology needed?" And "Who will use this technology?" are paramount to its success.

Therefore, the platform was submitted to a proof of concept called SWOT analysis. As the name implies, this test evaluates Strengths, Weaknesses, Opportunities and Threats to prove both the viability and usability of the developed solution. Thus, the presented technique evaluates both the internal environment and the external environment of a solution or even of the organization.

Table 1 presents the SWOT analysis performed for the developed platform.

Parameter	**Analysis**
Strengths	- Centralization of information - Fast error detection - Centralized activity history - High usability - Easy maintenance - High scalability - Ease of adaptation and evolution
Weaknesses	- Dependency on CHUP's internal network - Complexity in historical research, namely in dates - Delay in executing complex requests
Opportunities	- Construction of indicators that allow detection of error patterns - Direct connection to agent software for possible error correction - Imminent need for smart agent monitoring -Improve the quality and effectiveness of CHUP services
Threats	- Modification of the structures or databases that feed the application. - User rejection of new technologies - Internet network connectivity issues - Competition with new technological innovations that may appear

Table 1: SWOT Analysis

6 Conclusions

The implementation of interoperability issues in healthcare institutions is quite challenging due to the heterogeneity of the tasks, activities, information systems and health professionals involved, the diversity of organizational structures, and the complexity and difficulties in adopting and managing changes in hospital settings. AIDA was developed to allow the dissemination and integration of information generated in the healthcare environment and is currently being used by several Portuguese hospitals, including CHUP. The institutions that use the AIDA platform have already tackled many of their interoperability problems, since this is a platform responsible for interconnecting the services 24 hours a day, every day of the year. Thus, the occurrence of a failure in any of the agents that make up the AIDA platform brings severe costs to the institution and eventually to patients' life. Hence, the AIDA platform needs parallel systems to predict and avoid failures as well as to monitor the activity of the intelligent agents.

In this sense the developed platform monitors the behavior of the intelligent agents that constitute of AIDA platform. The monitoring platform responds to several requirements such as:

- Real-time monitoring of intelligent agents (individually and collectively);
- Exhibition of statistical metrics for consultation and knowledge construction;
- Consultation of past events using date filters;
- Extraction of relevant insights about agent's behavior through charts and dashboards;
- Identification of root causes of poor performance, errors and inconsistencies.

With this platform, managers will be able to ensure the proper functioning of the intelligent agents that make up the AIDA and, consequently, ensure excellence in the provision of healthcare to the patient. ReactJS, a JavaScript library for building user interfaces, was chosen to give body and shape to the platform, as it is a modern and powerful tool that is taking over the frontend development because of its fast rendering due to the existence of a virtual DOM and the ability to reuse and combine components. The backend of the platform is in NodeJS and ensure the connection between the Oracle database and the interface

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References

1. Brandão, A., Pereira, E., Esteves, M., Portela, F., Santos, M., Abelha, A., Machado, J.: A Benchmarking Analysis of Open-Source Business Intelligence Tools in Healthcare Environments. Information. 7, 57 (2016). Simulation and Real Time Applications. (2013).
2. Cardoso, L.: Desenvolvimento de uma Plataforma baseada em Agentes para a Interoperabilidade, (2013).
3. Cardoso, L., Martins, F., Portela, F., Santos, M., Abelha, A., Machado, J.: A Multiagent Platform for Hospital Interoperability. Ambient Intelligence - Software and Applications Advances in Intelligent Systems and Computing. 127-134 (2014).
4. Cardoso, L., Martins, F., Portela, F., Santos, M., Abelha, A., Machado, J.: The Next Generation of Interoperability Agents in Healthcare. International Journal of Environmental Research and Public Health. 11, 5349-5371 (2014).
5. Cardoso, L., Martins, F., Quintas, C., Portela, F., Santos, M., Abelha, A., Machado, J.: Interoperability in Healthcare. Cloud Computing Applications for Quality Health Care Delivery Advances in Healthcare Information Systems and Administration. 689-714 (2014)
6. Cardoso, L., Martins, F., Quintas, C., Portela, F., Santos, M., Abelha, A., Machado, J.: Interoperability in Healthcare. Health Care Delivery and Clinical Science. 689-714 (2018).
7. Castaneda, C., Nalley, K., Mannion, C., Bhattacharyya, P., Blake, P., Pecora, A., Goy, A., Suh, K.S.: Clinical decision support systems for improving diagnostic accuracy and achieving precision medicine. Journal of Clinical Bioinformatics. 5, (2015).

8. Duarte, J., Salazar, M., Quintas, C., Santos, M., Neves, J., Abelha, A., Machado, J.: Data Quality Evaluation of Electronic Health Records in the Hospital Admission Process. 2010 IEEE/ACIS 9th International Conference on Computer and Information Science. (2010).
9. Foshay, N., Kuziemsky, C.: Towards an implementation framework for business intelligence in healthcare. International Journal of Information Management. 34, 20-27 (2014).
10. Haux, R.: Health information systems - past, present, future. International Journal of Medical Informatics. 75, 268-281 (2006).
11. Isern, D., Sanchez, D., Moreno, A.: Agents applied in health care: A review. International Journal of Medical Informatics. 79, 145-166 (2010).
12. Jennings, N.R., Wooldridge, M.: Applications of Intelligent Agents. Agent Technology. 3- 28 (1998).
13. Lenz, R., Reichert, M.: IT support for healthcare processes - premises, challenges, perspectives. Data Knowledge Engineering. 61, 39-58 (2007).
14. Machado, J., Abelha, A., Neves, J., Santos, M.: Ambient intelligence in medicine. 2006 IEEE Biomedical Circuits and Systems Conference. 95-97 (2006).
15. Machado, J., Abelha, A., Novais, P., Neves, J., Neves, J.: Quality of service in healthcare units. International Journal of Computer Aided Engineering and Technology. 2, 436 (2010).
16. Machado, J. M., Miranda, M., Gonçalves, P., Abelha, A., Neves, J., Marques, J. A.: AIDATrace - Interoperation Platform for Active Monitoring in Healthcare Environments, ISC, Eurosis (2010).
17. Martins, F., Cardoso, L., Esteves, M., Machado, J., Abelha, A.: An Agent-Based RFID Monitoring System for Healthcare. Advances in Intelligent Systems and Computing. 407-416 (2017).
18. Miranda, M., Pontes, G., Abelha, A., Neves, J., Machado, J.: Agent based interoperability in hospital information systems. 2012 5th International Conference on Biomedical Engineering and Informatics. (2012).
19. Musen, M.A., Middleton, B., Greenes, R.A.: Clinical Decision-Support Systems. Biomedical Informatics. 643-674 (2014).
20. Peixoto, H., Santos, M., Abelha, A., Machado, J.: Intelligence in Interoperability with AIDA. Lecture Notes in Computer Science. 264-273 (2012).
21. Pontes, G., Portela, C., Rodrigues, R., Santos, M., Neves, J., Abelha, A., Machado, J.: Modeling Intelligent Agents to Integrate a Patient Monitoring System. Trends in Practical Applications of Agents and Multiagent Systems. 139-146 (2013).
22. Rodrigues, R., Gonçalves, P., Miranda, M., Portela, F., Santos, M., Neves, J., Abelha, A., Machado, J.: Monitoring intelligent system for the Intensive Care Unit using RFID and multi-agent systems. 2012 IEEE International Conference on Industrial Engineering and Engineering Management. (2012).
23. Shojania, K.G., Duncan, B.W., McDonald, K.M., Wachter, R.M., Markowitz, A.J.: Making health care safer: a critical analysis of patient safety practices. Evid Rep Technol Assess (Summ). 43, 668 (2001).
24. Taylor, S., Todd, P.A.: Understanding Information Technology Usage: A Test of Competing Models. Information Systems Research. 6, 144-176 (1995).
25. Tolk, A.: Interoperability, Composability, and Their Implications for Distributed Simulation: Towards Mathematical Foundations of Simulation Interoperability. 2013 IEEE/ACM 17th International Symposium on Distributed.